Office of Naval Research Graduate Traineeship Award in Ocean Acoustics for Srinivasan Jagannathan

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LONG-TERM GOALS

1. Dynamics of clutter

The long term goal of this research is to develop a general method to determine the dynamics of clutter observed in sonar imagery such as Ocean Acoustic Waveguide Remote Sensing[1] (OAWRS). We aim to use waveguide remote sensing techniques to obtain time varying density images of clutter in a shallow water environment, and use these images to develop a robust technique to invert for clutter dynamics. Currently there is no robust method to determine the dynamics of clutter from density images. Our research aims to ultimately distinguish clutter from intended targets by exploiting the differences in their dynamics.

2. Hurricane classification

The long term goal of this research is to analyze underwater noise measurements in the vicinity of a hurricane to help in surface wind speed estimation.

OBJECTIVES

1. Dynamics of clutter

The primary objectives of the research are to:

- Characterize clutter in active sonar images.

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14. ABSTRACT
The long term goal of this research is to develop a general method to determine the dynamics of clutter observed in sonar imagery such as Ocean Acoustic Waveguide Remote Sensing1 (OAWRS). We aim to use waveguide remote sensing techniques to obtain time varying density images of clutter in a shallow water environment, and use these images to develop a robust technique to invert for clutter dynamics. Currently there is no robust method to determine the dynamics of clutter from density images. Our research aims to ultimately distinguish clutter from intended targets by exploiting the differences in their dynamics.

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- Develop a robust method to invert for the dynamics of clutter from time varying OAWRS images.
- Invert for clutter velocity fields and dynamic forces driving clutter by applying the method to sequential OAWRS images from clutter experiments conducted in continental shelf environments.

2. Hurricane classification

The primary objectives of this research are

- Studying the characteristics and mechanisms of underwater ambient noise in high winds including hurricane conditions.
- Determine the destructive power of hurricanes from inexpensive underwater hydrophones.
- Determine the time period of surface gravity waves from underwater acoustic measurements.

APPROACH

To invert for the dynamics of clutter, we form a minimization problem for determining the velocity and forcing fields from sequential OAWRS images obtained from acoustic clutter experiments. To test the effectiveness of the method, we use images of fish areal density distribution obtained during the OAWRS 2003 Acoustic Clutter Experiment. Current methods[3] for determining velocity fields from sequential images are specific to certain types of incompressible motion. We aim to develop a more general method that is suitable for application to clutter motion estimation that usually involves compressible motion as well.

WORK COMPLETED

The research work in Fiscal Year 2008 was a great success in developing and applying a new, innovative *Minimum Energy Flow* (MEF) technique to determine velocity fields, that requires little knowledge of the mechanisms underlying the scatterer dynamics. The Minimum Energy Flow method also enables us to determine the force fields driving motion, from time varying density images formed using long range waveguide remote sensing in a continental shelf environment.

The method has significant advantages over established techniques such as *Optical Flow*[3]. First, it can deal with compressible motion which is a common characteristic of density images. Second, it requires little knowledge of the underlying mechanisms that drive the motion field. The method has been applied to data from the OAWRS 2003 Acoustic Clutter Experiment. The time varying density data of fish groups from this experiment, has been studied in detail[1]. Quantitative measures of velocity fields explaining behavioral phenomena such as translation of fish groups are shown. Pressure gradient and force fields that drive the velocity field are also calculated. The method has also been applied to data from another recent experiment conducted in Georges bank [4].

We have analyzed data from the OAWRS 2003 Acoustic Clutter Experiment[1] to demonstrate OAWRS capability to remotely sense scattering characterisics of bio-clutter and have theoretically shown how the OAWRS approach to remotely image bio-clutter can be used in a number of continental shelves around the world[9]. We have also analyzed data from the Gulf of Maine 2006 experiment[2] to quantify clutter emergence in active sonar systems and documented the diurnal variations in the spatial and temporal distribution of bio-clutter in a region with varied oceanography and bathymetry such as the Gulf of Maine.

During Fiscal Year 2008, we deployed hydrophones off Isla Socorro, Mexico, to record underwater noise. We have successfully retrieved the data from the sensors and are analyzing it.

RESULTS

Traditional methods of motion estimation from time varying images such as *Optical Flow* depend on a “constant brightness assumption” where the image pixel value is assumed to be constant as the images evolve. Sonar images that describe clutter, however, usually describe undelying processes that involve deformable or compressible motion. Also, in sonar applications, we do not know the underlying principles that govern the motion observed in the images. There is thus a need to develop a general approach in dealing with inverting clutter dynamics from time varying density images.

The MEF technique that we have developed, can deal with both incompressible and compressible motion, since it employs a compressible continuity equation to describe the motion field. By using a Least Action Principle to describe the motion, we also ensure that MEF requires minimum *apriori* knowledge of the principles governing the motion of clutter.

We applied MEF to density images obtained from the OAWRS 2003 Acoustic Clutter Experiment. Using this method we are able to use the time variation in spatial density distribution to estimate the velocity field in these images. Using the computed velocity fields we are now able to quantify the behavioral dynamics of biologically induced clutter such as fish groups over large spatial scales for the first time. We showed that (1) typically, the magnitudes of the clutter velocities are on the order of the typical fish velocities[5], (2) the major types of fish-shoal motion such as translation, coalescence, spitting, contraction and expansion can be explained by quantifying (environmental) pressures and their gradients computed using MEF. The pressures and forces acting on fish shoals is computed by modeling the fish shoal as a compressible fluid and using a Navier-Stokes equation based approach. These pressure gradients are a measure of the typical accelerations experienced by the fish groups that ultimately drive the behavior. Quantifying these dynamical quantities now enables us to model motion arising from bio-clutter such as large fish shoals as well as to predict the short time span behavior of these groups ultimately enabling clutter classification.

Our analysis of active sonar data from the 2003 Geoclutter Experiment showed that the fish shoals imaged by OAWRS were stronger scatterers than theoretically predicted[9]. We also showed that OAWRS can be used in a variety of continental shelves around the world to characterize bio-clutter.

Clutter emergence in active sonar system was quantified by analyzing wide-area sonar images from the 2006 Gulf of Maine Experiment[2]. The spatial and temporal distribution of bio-clutter was documented over an entire diel cycle for two weeks in the Gulf of Maine. Our analysis showed that, as with the New Jersey Continental Shelf[1], fish shoals were the major cause of clutter in tactical navy sonar systems even in a region with varied bathymetry and oceanography, such as Gulf of Maine. We also showed that clutter identification and mitigation is possible through a systematic observation of its evolution over time and space.

We successfully deployed two hydrophones off Isla Socorro, Mexico, to record underwater noise. This was done in collaboration with the Mexican navy. The hydrophones were let to record noise for a year, and we have retrieved underwater noise data recorded during that period. We are now analyzing the data to correlate the underwater noise intensity with surface wind speed. Isla Socorro was chosen because of the high frequency of hurricanes that pass by the island. We expect to correlate the noise intensity with surface wind speeds.

IMPACT/APPLICATIONS

Estimation of the kinematic and dynamic parameters from images is very important to predict behavior and ultimately help in classification of the different targets images using long range sonar. Man made objects tend to have a constant and predictable velocity field, whereas biologically induced clutter have more spatial variability in their velocity distribution. Minimum Energy Flow helps in identifying these trends in velocity distribution and thus helps in clutter classification.

Correlating underwater noise intensity with surface wind speed gives us a great tool to estimate wind speeds in hurricanes, without having to use sophisticatd "hurricane hunting" aircraft. Earlier work by Evans *et. al* [6] show the existence of a power law relationship between underwater noise intensity and the surface wind speed, at low wind speeds (< 10 m/s). Recently, Wilson and Makris[7,8] have shown the existence of the same power law relationship between the underwater noise intensity and the surface wind speed, even at high wind speeds in hurricane conditions. Analyzing the underwater noise data from Isla Socorro would lend futher proof to their work.

PUBLICATIONS

Journal papers

- S. Jagannathan, I. Bertsatos, D. Symonds, T. Chen, H.T. Nia, A.D. Jain, M. Andrews, Z. Gong, R.W. Nero, L. Ngor, J.M. Jech, O.R. Godø, S. Lee, P. Ratilal, N.C. Makris, "Ocean Waveguide Acoustic Remote Sensing (OAWRS) of Marine Ecosystems," Accepted for publication in *MEPS* special issue on Ocean Acoustics.

- N.C. Makris, P. Ratilal, S. Jagannathan, Z. Gong, M. Andrews, I. Bertsatos, O.R. Godø, R.W. Nero, J.M. Jech, "Critical population density triggers rapid formation of vast oceanic fish shoals," *Science* 323 (5922), pp 1734.
- S. Jagannathan, B. Horn, P. Ratilal and N. C. Makris, "Velocity estimation and prediction from time-varying density images," In preparation.
- N.C. Makris, P. Ratilal, D. Symonds, S. Jagannathan, S. Lee, R.W. Nero, "Fish population and behavior revealed by instantaneous continental shelf scale imaging," *Science* 311, pp 660.

Conference presentations

- S. Jagannathan, P. Ratilal, B. Horn, N.C. Makris, "Fish velocity and pressure gradient fields from acoustic flow in sonar images, with application to large fish shoals imaged by OAWRS", SEAFACTS, Bergen, Norway, 2008.
- S. Jagannathan, S. Lee, D. Symonds, P. Ratilal, N.C. Makris, "Estimating pressure gradients governing fish shoal dynamics over continental-shelf scales" *J. Acoust. Soc. Am.* 120, 3060, 2006.
- S. Jagannathan, D. Symonds, S. Lee, N.C. Makris, N. Donabed, P. Ratilal, "Tracking fish motion and behavior with acoustic flow" *J. Acoust. Soc. Am.* 119, 3435, 2006.

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[5] I. Huse, E. Ona (1996) *Int. Council Explor. Sea J. Mar. Sci.* **53**, 863.
[6] D.L.Evans *et. al* (1984) *J. Geophys. Res.* **89**, 3457.
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[8] J.D.Wilson, N.C.Makris (2008) *Geophys. Res. Lett.* **35**
[9] S. Jagannathan et al., "Ocean Waveguide Acoustic Remote Sensing (OAWRS) of Marine Ecosystems," Invited paper, Accepted for publication in *MEPS* special issue on Ocean Acoustics.